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The Sedentary Multi-Frequency Survey. I. Statistical Identification and Cosmological Properties of HBL BL Lacs

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ABSTRACT

We have assembled a multi-frequency database by cross-correlating the NVSS catalog of radio sources with the RASSBSC list of soft X-ray sources, obtaining optical magnitude estimates from the Palomar and UK Schmidt surveys as provided by the APM and COSMOS on-line services. By exploiting the nearly unique broad-band properties of High-Energy Peaked (HBL) BL Lacs we have statistically identified a sample of 218 objects that is expected to include about 85% of BL Lacs and that is therefore several times larger than all other published samples of HBLs. Using a subset (155 objects) that is radio flux limited and statistically well-defined we have derived the $V/V_{\rm m}$ distribution and the LogN-LogS of extreme HBLs ($f_{\rm x}/f_{\rm r} \geq 3\times10^{-10}$ erg cm^{-2} s^{-1} Jy^{-1}) down to 3.5 mJy. We find that the LogN-LogS flattens around 20 mJy and that $\langle V/V_{\rm m}\rangle = 0.42 \pm 0.02$. This extends to the radio band earlier results, based on much smaller X-ray selected samples, about the anomalous cosmological observational properties of HBL BL Lacs. A comparison with the expected radio LogN-LogS of all BL Lacs (based on a beaming model) shows that extreme HBLs make up roughly 2% of the BL Lac population, independently of radio flux. This result, together with the flatness of the radio logN-logS at low fluxes, is in contrast with the predictions of a recent model which assumes an anti-correlation between peak frequency and bolometric luminosity. This scenario would in fact result in an increasing dominance of HBLs at lower radio fluxes; an effect that, if at all present, must start at fluxes fainter than our survey limit. The extreme $f_{\rm x}/f_{\rm r}$ flux ratios and high X-ray fluxes of these BL Lacs makes them good candidate TeV sources, some of the brighter (and closer) ones possibly detectable with the current generation of Cerenkov telescopes. Statistical identification of sources based on their location in multi-parameter space, of the kind described here, will have to become commonplace with the advent of the many large, deep surveys at various frequencies currently scheduled or under construction.

Key words: BL Lacertae objects: galaxies, Active

1 INTRODUCTION

The recent widespread availability of large catalogs of astronomical objects (e.g., NVSS, Condon et al. 1998, FIRST, White et al. 1997 in the radio band, WGA, White, Giommi & Angelini 1994, ROSATSRC, Voges et al. 1994, and RASSBSC, Voges et al. 1996) combined with on-line services offering simple access to finding charts and magnitude estimates, is providing an unprecedented opportunity to carry out large and complex multi-frequency surveys, such as, for example, the DXRBS (Perlman et al. 1998) and the REX (Caccianiga et al. 1999). However, as in all traditional surveys, the initial multi-wavelength selection must be followed by optical spectroscopic identification of a very large number of candidates. This classical approach often requires extremely large amounts of telescope time and, consequently, very long times before the survey results can be secured. An alternative, much faster and by far less demanding, approach is the "statistical identification" of sources based on unique (or nearly unique) characteristics of some classes of sources in the multi-dimensional parameter space. We present here a multi-frequency survey based on archival/catalog data that makes use of statistical identification of a type of BL Lacertae objects that are known to possess a peculiar broad-band energy distribution.

Since their discovery, BL Lacs stood out from other types of extragalactic sources for their extreme and sometimes unique properties. These include large and rapid variability, high polarization, lack of emission lines etc. (e.g., Kollgaard 1994). Traditionally, BL Lacs were mostly found in radio surveys, but in the 1980s the discovery of many BL Lacs as serendipitous sources in X-ray images led to the division of this class into Radio selected and X-ray selected BL Lacs, the latter apparently showing somewhat less extreme properties (e.g., Stocke et al. 1985). Very recent observations, however, revealed that X-ray selected objects do show very large variability in their bolometric luminosity, sometimes accompanied with spectacular spectral changes (MKN 501, Pian et al. 1998, 1ES 2344+514, Giommi et al. 1999, MKN 421, Malizia et al. 1998, ON 321, Tagliaferri et al. 1998, PKS 2005-489, Tagliaferri et al. 1998).

A recent unified model (Padovani & Giommi 1995b) put forward a view where radio and X-ray discovered BL Lacs belong to the same basic population and are only distinguished by the peak of their synchrotron emission. Objects with synchrotron peak at low energy (typically in the Infra-Red) are generally found in radio surveys and are called LBLs (low energy peaked BL Lacs), while the rarer objects with synchrotron peak in the UV/X-ray band are called HBLs (high energy peaked BL Lacs), and are mainly selected in the X-ray band, where the maximum of their synchrotron power is emitted.

The space density of BL Lacs is intrinsically low. This makes them rare objects at nearly all frequencies, except in the gamma rays where, together with emission line Blazars, they are by far the most abundant component within the high galactic latitude population of sources. At even higher energies BL Lacs are the only extragalactic objects to populate the presently known TeV sky.

Synchrotron emission followed by inverse Compton scattering, combined with relativistic beaming is generally thought to be the mechanism responsible for the smooth emission over such a huge spectral range and for the extreme properties of these singular sources (Kollgaard 1994, Urry & Padovani 1995).

To date only about 400 BL Lac objects are known (Padovani & Giommi 1995a, Bade et al. 1998, Perlman et al. 1998, Laurent-Muehleisen et al. 1998). Because of their low surface density, sizable samples of BL Lacs can be constructed only from surveys covering large portions of the sky.

In this paper we report on the first results of a multi-frequency search entirely based on radio, optical, and X-ray archival data. Since this survey does not require optical identification before significant conclusions can be drawn, we have called it "sedentary." In particular, we extract a well defined (radio) flux-limited sample of HBLs from which we derive some of the cosmological properties of this type of objects. The work presented here is complementary to the DXRBS (Perlman et al. 1998) which instead concentrates on BL Lacs and other radio loud AGN with less extreme values of the X-ray to radio flux ratio (f_x/f_r) and that mainly cover the region of the $\alpha_{ox} - \alpha_{ro}$ plane occupied by less X-ray bright BL Lacs and by flat-spectrum radio quasars (FSRQ).

Throughout this paper we assume a Friedmann cosmology with $H_0 = 50\ Km\ s^{-1}\ Mpc^{-1}$ and $q_0 = 0$.

Table 1: Spurious matches in the NVSS/RASSBSC cross-correlation

Coordinates shift degrees	no. of spurious matches	percentage
2.0	470	12.7
-2.0	380	10.3
4.0	460	12.4
-4.0	421	11.4

2 THE RADIO/X-RAY CROSS-CORRELATION

The NVSS catalog of radio sources (Condon et al. 1998, version available in June 1998, including 1,807,316 entries), which reaches a minimum flux of 2.5 mJy but is complete down to 3.4 mJy, has been cross-correlated with the RASSBSC catalog (18,811 entries above 0.05 cts/s, Voges et al. 1996) of bright soft X-ray sources detected during the *ROSAT* All Sky Survey. The correlation has been carried out using the EXOSAT/HEASARC BROWSE software as implemented at the *BeppoSAX* Science Data Center (SDC, Giommi & Fiore 1998). The radius used for the correlation was 0.8 arcminutes, roughly corresponding to the largest X-ray position uncertainty for any source in the RASSBSC, although 90% of the error radii are less than 20 arcseconds in the RASSBSC and typically less than 5 arcseconds in the NVSS survey.

The cross-correlation resulted in 3505 RASSBSC sources (2900 of which at $|b| > 20°$) matching to 3702 entries in the NVSS. In $\sim 5\%$ of the cases (189 sources) more than one radio source was found within the correlation radius; in these cases we have assumed that the radio counterpart is the brightest candidate, or the closest to the X-ray position in case the radio fluxes did not differ by more than a factor of two. We note that the double-lobed sources discussed by Caccianiga et al. (1999) would in most cases be missed by our selection procedure. However, since we are concentrating on BL Lacs, this actually works in the direction of decreasing the contamination of our sample from objects other than BL Lacs.

Given that the number of sources involved is very large and that the X-ray error regions are not always small, we must evaluate the effects of spurious spatial coincidences that may occur with non-negligible frequency. The fraction of spurious matches can be estimated by shifting the coordinates of all the sources of one of the catalogs by a fixed amount and re-run the cross-correlation with the same correlation parameters. This procedure has been applied four times with different amounts of the coordinates shift. The results are reported in Table 1 where we see that the expected percentage of spurious matches in our fixed radius cross-correlation is around $10 - 13\%$.

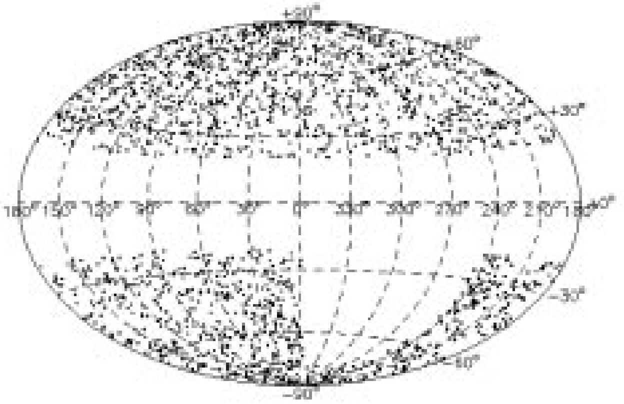

Figure 1. The 2074 NVSS/RASSBSC high-latitude ($|b| > 20°$), point-like (RASSBSC extent $<$ 30 arcseconds) sources for which an estimate of the optical magnitude is available are plotted in galactic coordinates. The portion of sky covered reflects the coverage of the NVSS ($\delta > -40°$) and of the RASSBSC (92% of the sky). The sources are spread over approximately one half of the sky.

This fraction can be significantly reduced by removing those matches for which the distance between the radio and X-ray positions is much larger than the combined NVSS/RASSBSC positional error (when this is significantly smaller than the fixed 0.8 arcminutes radius used for the cross-correlation). For a radio/X-ray position distance that is 2.5 times larger than the (1σ) expected value this operation removes 412 entries, a number that is close to that expected from spurious associations (see Tab. 1). We conclude that the remaining (3093) matches should include only a very small percentage ($\lesssim 1\%$) of spurious associations. Finally, since we are only interested in high galactic latitude, point-like, sources we removed all RASSBSC entries with extension larger than 30 arcseconds (e.g., Fisher et al. 1998) and with $|b| < 20°$. The final sample includes 2166 objects.

Our sample of NVSS/RASS sources includes previously known astronomical objects. These have been identified by cross-correlating the sample with several astronomical catalogs available within BROWSE (e.g. AGN, HD, SAO, VSTARS, CVCAT, EMSS, WGACAT, etc.) and by using NED. This operation led to the identification of over 1000 previously known sources. Optical magnitudes and other parameters for all the identified objects have been added to our database using the values listed in the catalogs or provided by NED. For the remaining sources we have attempted to obtain an estimate of their optical magnitude by means of the COSMOS (Yentis et al. 1992) and the APM (Irwin, Maddox, & McMahon 1994) on-line services. This was achieved through a procedure that automatically retrieves, from the on-line services, a list of potential optical counterparts lying within 9 arcseconds from the more accurate NVSS position. In most cases only one candidate optical counterpart is located within the combined optical-NVSS uncertainty region, which is typically 5 arcseconds in radius. When this occurs we assume that the only candidate present is the optical counterpart of the radio/X-ray source. When more than one optical object is inside in the combined optical/NVSS error region we assume that the optical counterpart is the brightest source.

To take into account the fact that the uncertainties in the radio position of the NVSS increase at smaller fluxes, we have repeated the COSMOS/APM search for the objects without optical counterpart using a 15 arcseconds radius. This has resulted in several additional radio/optical associations, reducing to only 92 (out of a total of 2166) the number of cases where no optical counterpart could be found. Some of these could be the result of accidental radio-X-ray associations, which are expected to be present at the $\sim$ 1 percent level; other can be associated to problematic optical plate regions (e.g., plate impurities, regions close to very bright stars, etc.; see below for the case of the HBL sample). In other cases the optical counterpart could indeed be very faint and below the plates sensitivity limit.

V magnitudes where estimated from O and E magnitudes obtained from the APM for the northern hemisphere and from the COSMOS B_J magnitudes as follows. When $O-E$ was available (APM) we converted O magnitudes first to B magnitudes using $B = O - 0.119 \times (O-E)$ (Ciliegi et al. 1996). We then derived $B-R$ from $O-E$ following Gregg et al. (1996), and $B-V$ from $B-R$ using the standard formulae given by Zombeck (1990; when $O-E$ was not available we have simply assumed $O-V = 0.5$). Finally, $V = B-(B-V)$. In the case of the COSMOS B_J magnitudes, where no color information is given, we simply assumed $B-V = 0.5$. Galactic extinction (A_V) was estimated following Wilkes et al. (1994) from the value of the hydrogen column density along the line of sight in units of atoms cm^{-2}, N_H, derived from the Dickey and Lockman (1990) 21cm radio data. (Namely, $A_V = 3 \times [\max(0, (N_H \times 1.99 \times 10^{-22} - 0.055)]$.) We have thus been able to obtain reddening-corrected magnitude estimates for 2074 sources at $|b| > 20°$.

External accuracy for the APM magnitudes is estimated to be ~ 0.3 magnitudes for the fainter images, reaching ~ 1 magnitude for bright images. We assume a value of 0.5 but note that for our purposes this is a conservative estimate. The sources we are interested in, in fact, have $\alpha_{\rm ro} > 0.2$ (see below) and are therefore relatively faint in the optical.

We note that the completeness limits of the plates which were scanned to produce the APM and COSMOS catalogs are $O \sim 21.5$ and $B_J \sim 22.5$ for the northern and southern sky respectively (Irwin et al. 1994; see also the on-line description of the APM catalogues at *http://www.ast.cam.ac.uk/~apmcat/*). This translates to $V_{\rm lim} \sim 21$ and 22.

2.1 The $\alpha_{\rm ox} - \alpha_{\rm ro}$ diagram

The RASSBSC catalog includes all RASS sources detected at a count rate larger than 0.05 cts/s (although it is only complete down to 0.1 cts/s). This count rate translates into different X-ray flux limits depending on the amount of N_H present along the line of sight and on the assumed sources' spectral shape. For our database we calculate X-ray fluxes assuming a power law spectrum with energy slope $\alpha_{\rm x} = 1.1$ (a value that is appropriate for high $f_{\rm x}/f_{\rm r}$ BL Lacs, Padovani & Giommi 1996) and N_H as derived from the Dickey and Lockman (1990) 21cm radio data.

With the inclusion of X-ray fluxes our multi-frequency database holds information on radio, optical and X-ray fluxes for a large fraction of the NVSS/RASSBSC sources.

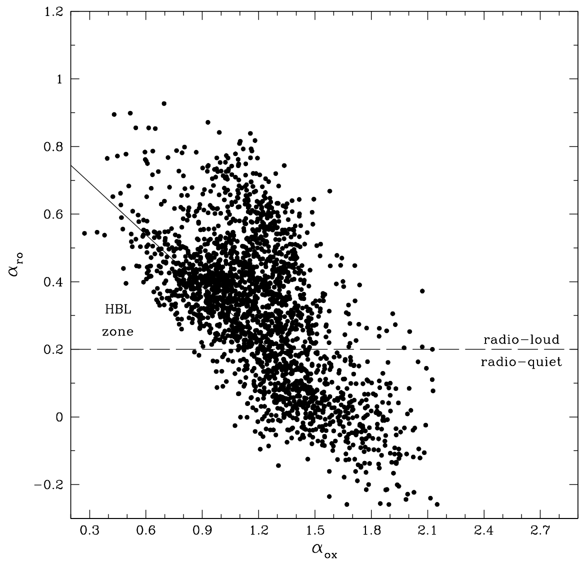

Figure 2. The 2074 high-latitude objects in our sample of NVSS/RASSBSC sources for which an estimate of the optical magnitude is available are plotted in the $\alpha_{ox} - \alpha_{ro}$ plane. The dashed line at $\alpha_{ro} = 0.2$ is our assumed division between radio-loud and radio-quiet AGN. Very few BL Lacs fall below this line. The solid line represents the locus of $\alpha_{rx} = 0.56$, which is equivalent to an X-ray-to-radio flux ratio $f_x/f_r = 3 \times 10^{-10}$ erg cm^{-2} s^{-1} Jy^{-1}. The triangular region delimited by the two lines (HBL zone) includes mostly BL Lacs (see text for details). For ease of comparison the scale is the same as Fig. 3.

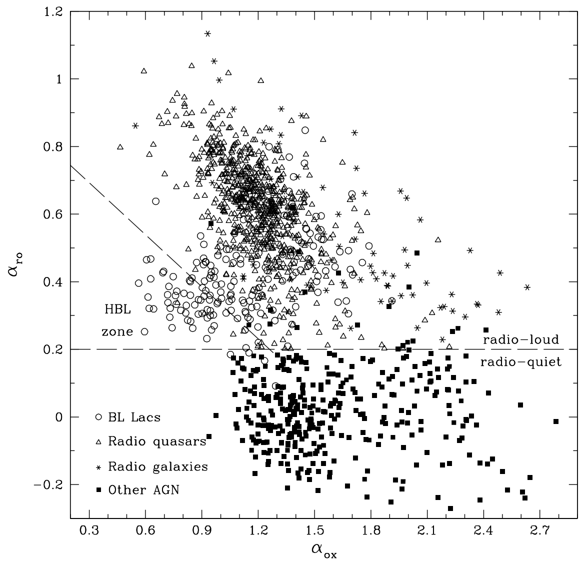

Figure 3. The $\alpha_{ox} - \alpha_{ro}$ diagram of 1362 AGN for which we could find radio, optical, and X-ray data from the literature. These come from the multifrequency AGN catalogue based on Véron-Cetty & Véron (1996) and described by Padovani, Giommi & Fiore (1997b). Open circles represent BL Lacs; open triangles are radio quasars; asterisks are radio galaxies, and filled squares are other types of emission lines AGN. The dashed line at $\alpha_{ro} = 0.2$ is our assumed division between radio-loud and radio-quiet AGN. Very few BL Lacs fall below this line. The solid line represents the locus of $\alpha_{rx} = 0.56$, which is equivalent to an X-ray-to-radio flux ratio $f_x/f_r = 3 \times 10^{-10}$ erg cm^{-2} s^{-1} Jy^{-1}. The triangular region delimited by the two lines (HBL zone) includes mostly BL Lacs (see text for details).

We have used these data to calculate various derived quantities.

3 FILLING THE MULTI-DIMENSIONAL PARAMETER SPACE

Figure 2 shows the 2074 sources for which we have radio, optical and X-ray fluxes plotted in the $\alpha_{ox} - \alpha_{ro}$ plane. These are the usual effective spectral indices defined between the rest-frame frequencies of 5 GHz, 5000 Å, and 1 keV. X-ray and optical fluxes have been corrected for Galactic absorption. The k-correction for sources without redshift information has been derived by assuming a redshift typical for the f_x/f_r value of the object (namely, z = 1, 0.5 and 0.25 for $f_x/f_r < 10^{-12}$, $10^{-12} < f_x/f_r < 3 \times 10^{-11}$, and $f_x/f_r > 3 \times 10^{-11}$ erg cm^{-2} s^{-1} Jy^{-1}respectively, as derived from the known objects in our database). The NVSS radio fluxes (at 1.4 GHz) were converted to fluxes at 5 GHz by assuming $\alpha_r = 0.2$, a value which is appropriate for HBLs. Similarly, $\alpha_o = 0.65$ was assumed (Falomo, Scarpa & Bersanelli 1994).

Uncertainties on the α_{ox}, α_{ro}, and f_x/f_r values will arise because of the non-simultaneity of the flux measurements and because of intrinsic uncertainties. Large flux variations, especially in the optical and X-ray band, can lead to $\Delta\alpha_{ox}$ up to 0.2-0.3 and to $\Delta\alpha_{ro} \lesssim 0.15$ Uncertainties due to flux measurements are expected to be smaller since NVSS radio fluxes are typically good to better than $\sim 10\%$ and RASS-BSC count rates have on average 20% uncertainties. Adding a 0.5 magnitude error in the optical band (see previous subsection) gives these typical uncertainties: $\Delta\alpha_{ox} \sim 0.08$, $\Delta\alpha_{ro} \lesssim 0.04$, and $\Delta f_x/f_r \lesssim 22\%$.

No large previously unpopulated regions of the $\alpha_{ox} - \alpha_{ro}$ plane are filled by our NVSS/RASSBSC sources in the region which is defined by our survey limits (i.e., $f_x \gtrsim 6 \times 10^{-13}$ erg cm^{-2} s^{-1}, $f_r > 2.5$ mJy, $V \lesssim 21 - 22$). This indicates that if new source types showing peculiar and previously unknown broad-band spectrum exist, their number must be small. Given the dynamical range of the two surveys we used, it is however apparent that our selection method favors objects towards the lower left corner of the $\alpha_{ox} - \alpha_{ro}$ plane (compare Fig. 2 and 3).

The maximum density of sources in Fig. 2 is located roughly along a band of $\alpha_{ro} \sim 0.2 - 0.4$ (which normally includes BL Lacs and flat spectrum radio quasars) and in a second region delimited by $1.1 \lesssim \alpha_{ox} \lesssim 1.8$ and $-0.1 \lesssim \alpha_{ro} \lesssim 0.2$ which is populated by radio-quiet AGN. The diagonal branch going from $\alpha_{ox} \sim 1.4, \alpha_{ro} \sim 0.3$ to $\alpha_{ox} \sim 1.0, \alpha_{ro} \sim 0.8$, normally populated by bright flat spectrum radio quasars and radio selected BL Lacs (LBLs), is also visible but not very pronounced due to the small number of objects with very bright radio flux and relatively low X-ray flux (i.e., most of the objects in this area would be too faint to be in the RASSBSC for a radio flux that is $\lesssim$ 1 Jy).

4 BUILDING A LARGE SAMPLE OF HBL BL LACS

Our goal here is to statistically select a large sample of HBL BL Lacs by exploiting the fact that this type of sources exhibit a peculiar and nearly unique radio-through-X-ray spectral energy distribution. It is well known (e.g., Stocke et al. 1988, 1991, Padovani, Giommi & Fiore 1997a) that there is a region in the $\alpha_{\rm ox} - \alpha_{\rm ro}$ plane that is almost exclusively populated by HBL BL Lac objects. Figure 3 shows the $\alpha_{\rm ox} - \alpha_{\rm ro}$ plot for 1362 known AGN with radio, optical, and X-ray data, taken from various catalogs. These come from the multifrequency AGN catalogue based on Véron-Cetty & Véron (1996) and described by Padovani, Giommi & Fiore (1997b). We can define an area in the figure which contains a very large fraction of BL Lacs, in particular BL Lacs with a synchrotron peak at UV/X-ray energies or HBL BL Lacs (given their relatively low values of $\alpha_{\rm ro}$ and $\alpha_{\rm ox}$: Padovani & Giommi 1995b). BL Lacs make up $\sim 91\%$ of all AGN in the triangular area delimited by $\alpha_{\rm ro} > 0.2$ (dashed line) and $f_{\rm x}/f_{\rm r} \gtrsim 3\times10^{-10}$ erg cm^{-2} s^{-1} Jy^{-1}* (or $\alpha_{\rm rx} \lesssim 0.56$: solid line), with $f_{\rm x}$ in the 0.3–3.5 keV band and $f_{\rm r}$ at 5 GHz. (This $f_{\rm x}/f_{\rm r}$ cut is a compromise between sample size and percentage of BL Lacs). We will call this area *the HBL zone*. It must be noted that these statements are strictly valid only in the flux range covered by the surveys used to build Figure 3. At fainter flux levels new populations of sources could emerge changing the simple picture described above. The X-ray, radio and optical fluxes of our NVSS/RASSBSC sources is well within the region of the parameter space covered by several other surveys, (e.g. the *Einstein* EMSS, the IPC Slew Survey, the EXOSAT HGLS and the HEAO1 surveys) so we feel that we can proceed safely.

For spectral indices typical of HBLs, it turns out that $f_{\rm x}(0.3 - 3.5~{\rm keV})/f_{\rm r}(5~{\rm GHz}) \sim 1.1~f_{\rm x}(0.1 - 2.4~{\rm keV})/f_{\rm r}(1.4~{\rm GHz})$. From now on, all $f_{\rm x}/f_{\rm r}$ ratios will refer to the *ROSAT* and NVSS bands.

For each unidentified object in the HBL zone in our multifrequency database we have retrieved an optical image from the on-line Digitized Sky Survey (DSS) service of the Space Telescope Science Institute (http://archive.stsci.edu/dss) and we have visually inspected it after plotting both the X-ray and radio error circles to search for obvious problems. In a few cases we found that the X-ray/radio association was clearly spurious due to the presence of a bright star ($V \lesssim 10$) non-coincident with the NVSS source. The star is most probably the counterpart of the X-ray emission. In other cases the RASS error box included a relatively bright galaxy ($V \sim 15 - 16$), presumably the source of the X-ray emission, and the position of the radio source was clearly inconsistent with that of the extended object. All these sources were removed from the sample.

After these checks our multifrequency database includes 234 sources in the HBL zone. From a cross-correlation with catalogs of known objects we see that 74 objects were already classified, 60 of these being previously known BL Lacs. Three other sources are galaxies in clusters (these could be BL Lacs in clusters, although the cluster gas emission could also provide the X-rays artificially moving the galaxy into the HBL zone), one is a galaxy listed in the CfA Redshift Catalog (Huchra et al. 1992), for which we have a redshift but no other information (its X-ray luminosity, however, is $L_{\rm x} \sim 3 \times 10^{44}$ erg s^{-1}, implying an active nucleus). In 10 cases our candidate HBLs are instead coincident with known emission line AGN. We have inspected the published optical spectra of these sources to check whether they could be misclassified BL Lacs. In all cases where this was possible (7/10) we have found strong and broad emission lines, typical of Seyfert galaxies or QSO. The presence of these sources (all of them close to the borders of the HBL zone, both in terms of $\alpha_{\rm ro}[\sim 0.25]$ and $\alpha_{\rm rx}[\sim 0.52]$) is probably due to one of the following reasons: 1. uncertainties in the estimation of the optical magnitude, which produces a scatter $\Delta\alpha_{\rm ro} \sim 0.08\Delta V$ (ΔV expressed in magnitudes); 2. large X-ray flares from quasars close to the borderline area; 3. clusters/groups of galaxies with size $\lesssim 30$ arcseconds; 4. radio-loud AGN with multifrequency spectra similar to those of HBLs (Padovani et al. 1997b; Perlman et al. 1998). These 10 sources will not be considered for the estimation of the $V/V_{\rm m}$ and logN-logS of HBLs.

As an additional criterion to reduce the contamination from non BL Lacs we excluded sources for which the RASS hardness ratio HR1 [defined as $(cts_{0.5-2.0keV} - cts_{0.1-0.4keV})/(cts_{0.5-2.0keV} + cts_{0.1-0.4keV})$] is softer than -0.5 (see Cao et al. 1998) thus removing sources with strong soft excess. This method can be efficiently applied to our extreme HBL candidates since their X-ray spectra are expected to be relatively flat ($\alpha_x \lesssim 1.5$; see Fig. 2 of Padovani & Giommi 1996), but not to less extreme (intermediate) BL Lacs which can be as steep as $\alpha_x \sim 3$. Within our sample only 8 sources have HR1 < -0.5. Six of these are unclassified but the two known sources are both emission line AGN.

The percentage of confirmed BL Lacs among the previously identified sources in our sample ranges between 83 and 88% depending on whether the galaxies in clusters are actually BL Lacs or spurious associations. This fraction grows to $95 - 100\%$ by imposing the more restrictive limits $f_{\rm x}/f_{\rm r} > 5 \times 10^{-10}$ and $\alpha_{\rm ro} > 0.25$ but at the cost of nearly halving the sample. This effect could simply be due to the fact that the percentual errors in the flux values become larger near the survey limits, causing some neighbouring objects to cross the border. In fact, the fraction of BL Lacs becomes 95% for $f_{\rm x} > 5\times10^{-12}$ erg cm^{-2} s^{-1}and 100% for $f_{\rm x} > 1 \times 10^{-11}$ erg cm^{-2} s^{-1}. It is difficult however, to distinguish between the effect of larger errors at faint fluxes and a real change in the underlying population as a function of flux. If there is such a population change within the flux range considered in this work it must be limited to a small percentage.

The statistical identification method described in this paper could also be applied to samples with somewhat less extreme values of $f_{\rm x}/f_{\rm r}$ than those considered here. In this case the efficiency decreases but not very rapidly. For example, a cut at $f_{\rm x}/f_{\rm r} \geq 3 \times 10^{-11}$ would result in a sample in which $\sim 61\%$ of identified objects are BL Lacs.

* The units of this ratio are certainly "non-standard" but those of the numerator and denominator are, so that this ratio is easily translated in terms of "observed" quantities. $\alpha_{\rm rx}$, on the other hand, requires redshift information, not available for most of our objects, and 1 keV fluxes, which are more dependent on the precise value of the X-ray spectral index than broad-band X-ray fluxes.

4.1 A well-defined radio flux limited sample of HBL BL Lacs

The sample of 218 sources described in the previous paragraph includes a very high percentage of HBL BL Lacs and therefore can be used to select a very large sample of HBL BL Lacs. This sample is much larger than the presently available X-ray selected samples which include typically only $30-40$ objects. The definition criteria used however are not strict enough to allow detailed statistical analysis. In this paragraph we define a flux-limited subsample that can be used for statistical purposes. This restricted sample is defined by the following conditions:

(i) $f_x/f_r \geq 3 \times 10^{-10}$ erg cm^{-2} s^{-1} Jy^{-1};
(ii) $f_r \geq 3.5$ mJy;
(iii) RASSBSC count rate ≥ 0.1 cts/s;
(iv) $\alpha_{ro} > 0.2$;
(v) $V \leq 21$;
(vi) $|b| > 20°$;

Conditions i) and ii) make this a radio flux limited sample of extreme HBL BL Lacs. The resulting limiting X-ray flux is in fact $f_x \geq 1.05 \times 10^{-12}$ erg cm^{-2} s^{-1}and there are no sources in our sample with $f_x/f_r \geq 3 \times 10^{-10}$ erg cm^{-2} s^{-1} Jy^{-1}and count rate ≥ 0.1 cts/s [condition iii)] below this limit. In other words, our survey has detected all objects with $f_x/f_r \geq 3 \times 10^{-10}$ erg cm^{-2} s^{-1} Jy^{-1}and $f_r \geq 3.5$ mJy in the area we cover (see next section). (Note that we *have not* detected all objects with $f_x/f_r \geq 3\times10^{-10}$ erg cm^{-2} s^{-1} Jy^{-1}and $f_x \geq 1.05\times10^{-12}$ erg cm^{-2} s^{-1}, as we miss all sources with $f_r < 3.5$ mJy. Our survey then is not complete for extreme HBLs in the X-ray band.) Condition iii) ensures that the coverage of the RASSBSC catalog (92% of the sky) also applies to our sample. Condition iv) (which excludes "radio-quiet" sources) makes sure that our candidates are fully within the HBL zone. Relaxing this condition would include a few more BL Lacs but at the expenses of a large contamination from other AGN classes just below the dividing line (see Figs. 2 and 3). The optical magnitudes of sources satisfying condition i – iv can reach values near 21 (our assumed completeness limit in the optical band) only in a very restricted corner of the parameter space, namely for $\alpha_{ro} \sim 0.5$ and f_r just above 3.5 mJy. For this reason we have added condition v), which makes the sample both radio and optically flux-limited, although the latter is a very mild limit. [We stress that only 2 empty fields satisfy conditions i), ii), iii), and vi). These fields remain "empty" even in the second generation scans of the DSS, which are deeper than the first one. This shows that the optical counterparts are safely below are assumed value of $V_{lim} = 21$.] Finally condition vi) simply restricts our sample to high galactic latitude sky regions. Conditions i) through vi) applied to our multi-frequency database define a set of 155 objects. The main steps that have led to this final sample are summarized in Table 2. A dedicated paper presenting finding charts, X-ray, optical, and radio fluxes for these sources is in preparation and will be published in the near future. Although our sample is far from being completely identified, it currently includes 58 BL Lacs and its HBL content is expected to be $\sim 85\%$. Taking this limitation in mind in the following sections we use this well-defined sample to investigate the statistical properties of HBL BL Lacs.

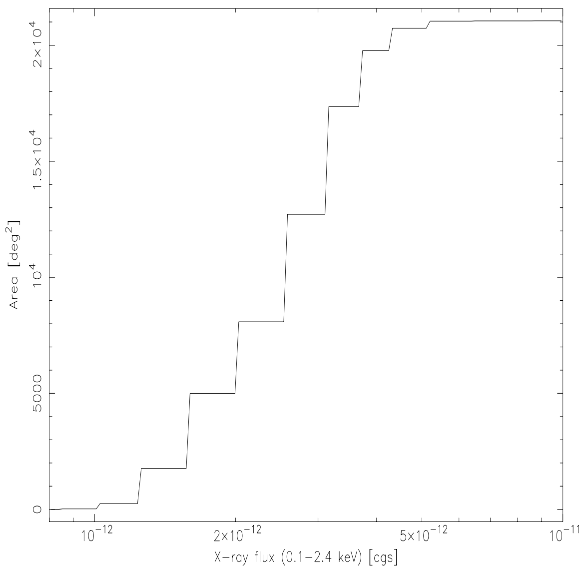

Figure 4. The sky coverage of the RASSBSC catalog for sources with $\delta > -40°$ and count rate in excess of 0.1 cts/s. The 0.1-2.4 keV flux has been calculated assuming a power law spectrum with energy index $\alpha = 1.1$ and absorption due to Galactic N_H as estimated from 21cm data.

4.2 The sky coverage of the sedentary survey

The sky coverage of our survey is given by the coverage of the NVSS (that is $\delta > -40°$), the galactic latitude cut ($|b| > 20°$), and by the sky coverage of the RASSBSC. The first two limits imply a survey area of 22,990 deg^2. The current, practically final, version of the NVSS includes 7,432 more sources than the one we used, which means we are roughly missing 0.4% of that area, for a total of 22,896 deg^2. The RASSBSC covers 92% of the sky at a limit of 0.1 cts/s (Voges et al. 1996) which is also the limit that we use (condition iii) in the definition of the HBL sample. The sky coverage of the RASSBSC, however is not simply a flat 92 percent of the sky since the varying amounts of N_H in different directions make the sensitivity a function of right ascension and declination. Assuming a power law spectrum with energy index of 1.1 and taking into account the absorption due to Galactic N_H (from the 21cm measurements of Dickey and Lockman 1990) for sources with $\delta > -40°$ and count rate ≥ 0.1 cts/s, we obtained the sky coverage shown in Fig. 4. The combined NVSS/RASSBSC sky coverage then amounts to a total area of $21,064$ deg^2 with a dependence on X-ray flux shown in Fig. 4.

5 THE RADIO LOGN-LOGS AND V/V_m DISTRIBUTION OF HBL BL LACS

The cosmological properties of X-ray selected BL Lacs (mostly HBLs, Giommi, Ansari & Micol 1995) have been reported as being different from those of all other types of AGN (Maccacaro et al. 1988, Morris et al. 1991, Wolter et al. 1994, Bade et al. 1998). Namely, it has been suggested that HBLs might be less luminous and/or less numerous at

Table 2: Main steps followed for the selection of the complete HBL sample

Number of objects	Operation	No. of remaining objects
1,807,316(NVSS)	Cross-correlation of NVSS and RASSBSC catalogues	—
18,811(RASSBSC)	(correlation radius=0.8 arcminutes)	3,505
3,505	Removal of matches with Δ position (radio/X-ray) $> 2.5\sigma$	3,093
3,093	Restrict to point-like (X-ray size $\leq 30''$) and high Galactic latitude sources ($\lvert b\rvert > 20°$)	2,166
2,166	Take sources with optical counterpart in APM/COSMOS	2,074
2,074	Take only sources in the HBL zone: $\alpha_{\rm ro}> 0.2$, $f_{\rm x}/f_{\rm r} > 3 \times 10^{-10}$ erg cm^{-2} s^{-1} Jy^{-1}	234
234	Removal of known broad line objects	224
224	Removal of sources with ROSAT hardness ratio HR1 < -0.5	218
218	Further conditions for a complete sample: ROSAT cts/s > 0.1, $f_{\rm r} > 3.5$ mJy, $V \leq 21$	155

high redshift, a behavior which is unique amongst extragalactic sources. To test if this result is also present in a radio flux limited sample we have calculated the LogN-LogS and the $V/V_{\rm m}$ distribution (Schmidt 1968), or more properly $V_{\rm e}/V_{\rm a}$ (Avni & Bachall 1980) for the sample defined in the previous section. The integral LogN-LogS of this sample of HBLs is shown in Fig. 5 together with a Euclidean power law with slope -1.5. A flattening at around ~ 20 mJy is evident from the plot. In the same figure we also plot the radio counts for the 8 EMSS HBLs in the Morris et al. (1991) sample (as updated by Rector, Stocke & Perlman 1999) with $f_{\rm x}/f_{\rm r} > 3\times10^{-10}$ and $f_{\rm r} > 1.7$ mJy (33% of the revised sample of 24 objects). In analogy to our sample, we can in fact derive a radio flux-limited subset of the EMSS BL Lacs. For an X-ray limit of 5×10^{-13} erg cm^{-2} s^{-1}, the condition $f_{\rm x}/f_{\rm r} > 3\times10^{-10}$ translates into a radio flux limit of 1.7 mJy. (In other words, despite being an X-ray flux limited sample, the EMSS could detect in the radio band all BL Lacs with $f_{\rm x}/f_{\rm r} > 3\times10^{-10}$ above $f_{\rm r} \sim 1.7$ mJy.) Only one of these extreme EMSS BL Lacs has a radio flux below this value and was therefore excluded. The remaining 8 objects make up a complete, albeit small, radio sample which can be compared to ours. The radio counts of these objects are in good agreement with ours, within their (rather large) uncertainties.

We also show the expected radio counts for all types of BL Lacs (top line) estimated from the radio luminosity function of Padovani & Giommi (1995b) that it is based on a beaming model and the radio luminosity function of Fanaroff-Riley type I radio galaxies (Urry et al. 1991), assumes no evolution, and fits the luminosity function of the 1 Jy BL Lacs. Note that the number of HBLs with $f_{\rm x}/f_{\rm r} > 3\times10^{-10}$ erg cm^{-2} s^{-1} Jy^{-1} is a roughly constant fraction ($\sim 1/50$) of the surface density of the whole population of BL Lacs.

We have next estimated the $V_{\rm e}/V_{\rm a}$ distribution of the HBLs in our sample. The exact value of $V_{\rm e}/V_{\rm a}$ of a source depends somewhat on its redshift thus introducing uncertainties in the $V_{\rm e}/V_{\rm a}$ distribution when z is not known and an estimate has to be used in its place. (For example, for $f/f_{\rm lim} = 2$, $V_{\rm e}/V_{\rm a}$ ranges between 0.35 and 0.6 for z which goes between 0 and 1.5. The dependence is weaker for lower values of $f/f_{\rm lim}$.) For all unidentified sources and for those objects identified with catalogued BL Lacs for which a redshift is not available we have assumed $z = 0.25$, a value close to the average redshift in the subsample of identified BL Lacs. We obtained $\langle V_{\rm e}/V_{\rm a}\rangle = 0.42\pm0.02$ implying that our radio flux limited sample of HBLs shows a significant deviation ($\sim 4\sigma$, $P > 99.9\%$) from a population of constant cosmological density.

To investigate the dependence of this result on redshift we have then calculated the $V_{\rm e}/V_{\rm a}$ distribution assuming $z = 0.5$ for the sources without redshift, a value which is more than a factor of 2 larger than the average redshift of the identified BL Lacs in the sample. The result is $\langle V_{\rm e}/V_{\rm a}\rangle = 0.45\pm0.02$, still more than 2σ lower than 0.5. As a comparative check we have also repeated the test on a sample selected imposing the same definition criteria used for the HBL sample except for point (iii) which has been changed to $\alpha_{\rm ro} < 0.15$. This new sample of radio quiet objects ($\alpha_{\rm ro} < 0.15$) includes 229 sources. Of these, 157 are identified, as follows: 14 stars (with relatively low $\alpha_{\rm ro}$ values), 13 galaxies, 2 BL Lacs, 1 Liner, 4 Seyfert 2s, and 123 broad-line objects (Seyfert 1 and quasars). The average redshift of the identified (extra-galactic) objects is 0.09. Most of the remaining unidentified sources are then expected to be nearby type 1 AGN. The radio flux in these sources is not necessarily directly related to the X-ray flux which is produced by a mechanism other then Synchrotron emission. The result is $\langle V_{\rm e}/V_{\rm a}\rangle = 0.53\pm0.02$ (for unidentified objects we have assumed $z = 0.09$, equal to the average value seen in the identified sources) consistent with a population of objects characterized by no cosmological evolution. The LogN-LogS function for this control sample is shown in Fig. 6, where no deviation from a Euclidean power law with slope -1.5 (dotted line) is apparent.

The expected contamination in the HBL sample due to the spurious presence of $\lesssim 15\%$ of emission line AGN should therefore increase the value of $\langle V_{\rm e}/V_{\rm a}\rangle$ since the measured $\langle V_{\rm e}/V_{\rm a}\rangle$ of these objects is larger than that of HBLs. The final value of $\langle V_{\rm e}/V_{\rm a}\rangle$ for our HBLs might therefore be even less than 0.42 once the sample is completely identified. We conclude that the flat LogN-LogS of HBLs and their low value of $\langle V_{\rm e}/V_{\rm a}\rangle$ is intrinsic to HBLs and not due to some unknown bias introduced by our selection method.

We have next calculated $\langle V_{\rm e}/V_{\rm a}\rangle$ for different values of the radio flux limit, keeping unaltered the other conditions detailed in Sect. 4.1. The results are reported in Table 3

Table 3: $\langle V_e/V_a \rangle$ of extreme HBLs for different radio flux limits

Radio flux limit mJy	$\langle V_e/V_a \rangle$	No of objects in sample
3.5	0.42 ± 0.02	155
5.0	0.43 ± 0.02	135
10	0.45 ± 0.03	84
20	0.49 ± 0.04	44

Table 4: $\langle V_e/V_a \rangle$ of radio quiet AGN for different radio flux limits

Radio flux limit mJy	$\langle V_e/V_a \rangle$	No of objects in sample
3.5	0.53 ± 0.02	229
5.0	0.51 ± 0.02	145
10	0.49 ± 0.04	59
20	0.50 ± 0.06	20

for HBLs and Table 4 for the control sample of radio quiet objects.

6 SELECTION EFFECTS

The sample selected on the basis of $f_x/f_r > 3 \times 10^{-10}$ erg cm^{-2} s^{-1} Jy^{-1} with the further restriction of $\alpha_{ro} > 0.2$ guarantees a very high fraction ($\sim 85\%$) of HBL BL Lacs without the need of spectroscopic classification that in some cases may introduce selection effects. One of these arises from the (4,000 Å) Ca II break in the optical spectrum of a candidate which is used to classify the object as a BL Lac or as a radio galaxy otherwise (e.g., Stocke et al. 1991, Perlman et al. 1998, Rector, Stocke and Perlman, 1999). Our method is independent of this and in principle can measure its reliability in distinguishing radio galaxies from BL Lacs once our sample is completely identified from follow-up optical spectroscopy. We note however that the contribution from the host galaxy in the optical band flattens the radio to optical index (α_{ro}) and could push a few BL Lacs with values close to our assumed limit ($\alpha_{ro} = 0.2$) into the radio-quiet AGN zone (see Fig. 3). Only four such objects are present amongst the 62 previously known BL Lacs with $f_x/f_r > 3 \times 10^{-10}$ erg cm^{-2} s^{-1} Jy^{-1}; their $\langle V_e/V_a \rangle$ value (0.34) is below average and their addition to the sample of 155 has a negligible impact on the radio counts and $\langle V_e/V_a \rangle$. Such a loss is numerically compensated by the residual percentage ($\sim 1\%$) of spurious radio/X-ray association (see Sect. 2), and by the small percentage of non BL Lacs expected to be present among the 93 unidentified objects in the HBL sample. As mentioned above, the contamination due to the spurious presence of $\sim 10\%$ of emission line AGN, should increase the value of $\langle V_e/V_a \rangle$ since the measured $\langle V_e/V_a \rangle$ of these objects is 0.53 ± 0.02.

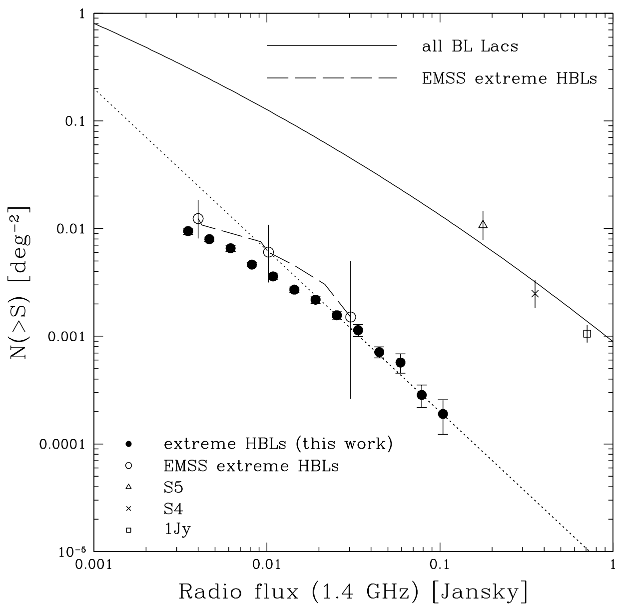

Figure 5. The radio LogN-LogS of the HBL sample ($f_x/f_r > 3 \times 10^{-10}$; filled circles). A flattening is apparent at around 20 mJy. The dotted line represents the Euclidean slope of -1.5. The radio counts of the 8 EMSS HBLs in the Morris et al. (1991) sample with $f_x/f_r > 3 \times 10^{-10}$ and $f_r > 1.7$ mJy are also shown (dashed line and open circles; see text for details); for clarity, error bars are given only for 3 representative points. The solid line represents the expected radio counts for all types of BL Lacs estimated from the radio luminosity function of Padovani & Giommi (1995b). The BL Lac surface density from the 1 Jy (open square), S4 (cross) and S5 (open triangle) surveys (the latter two still not completely identified), in excellent agreement with the prediction, are also shown. All data apart from our own HBLs (filled circles) have been converted from 5 GHz, assuming $\alpha_r = -0.27$ for the 1 Jy, S4, S5 points and beaming prediction and $\alpha_r = 0.2$ for the EMSS HBLs.

A somewhat related issue is that of the so-called Browne & Marchã effect. Browne & Marchã (1993) suggested that optically faint BL Lacs might go unrecognized as they could be swamped by the light of the host galaxy, which is typically a bright elliptical. However, we do not think that this has much influence on our HBL sample, as our X-ray flux limit is relatively high, above the value below which this effect starts to become severe (see Fig. 5 of Browne & Marchã 1993)[†]. One could argue that such objects, if they existed, might have $\alpha_{ro} < 0.2$ due to the galaxy component. We then looked for previously known objects without strong, broad lines, with relatively high radio power ($P > 3 \times 10^{23}$ W Hz^{-1}, typical of Fanaroff-Riley type I radio galaxies), and $0 < \alpha_{ro} < 0.2$ (i.e., with a galaxy component up to 2.5 magnitudes brighter than the BL Lac component). We found only one, a 15th magnitude CD galaxy at $z = 0.111$.

Finally, we have checked how many good matches could

† Note that although our sample is radio-selected, we have to use the Browne & Marchã predictions for the X-ray case, as they use an α_{ox} distribution which is similar to that of our sources, all HBLs.

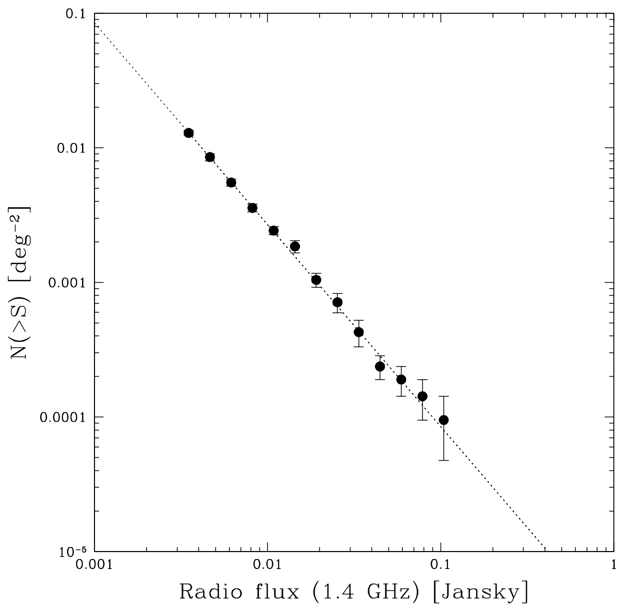

Figure 6. The LogN-LogS of the control sample of 229 radio quiet AGN with $f_x/f_r > 3 \times 10^{-10}$. The counts are consistent with the Euclidean slope of -1.5 (dotted line)

have been contaminated by the accidental presence of an unrelated optical source in the radio error region for our sample with $f_x/f_r > 3 \times 10^{-10}$ erg cm^{-2} s^{-1} Jy^{-1}. To this end we have re-run the automatic magnitude requests procedure from the COSMOS/APM services after shifting all radio coordinates by a fixed amount. We found that only in a tiny number of cases ($\sim 2-3$ in the entire sample) a bright ($V < 16$) spurious optical source could have moved a good candidate past the radio quiet line ($\alpha_{ro} < 0.2$). Conversely, a truly empty field (i.e., no counterpart of the radio source down to V = 21) could have been included in the sample because of the accidental presence of an unrelated optical source only in less than 10% of the cases. However, since the number of empty fields is small this contamination is expected to be negligible.

7 DISCUSSION AND CONCLUSIONS

By cross-correlating public catalogs we have assembled a multi-frequency database of high Galactic latitude sources which includes 2074 radio–optical–X-ray sources, 59% of them still unidentified. The source distribution in the $\alpha_{ox} - \alpha_{ro}$ plane (Fig. 2) follows a well known pattern (Stocke et al. 1991, Padovani et al. 1997a) with a horizontal band centered around $\alpha_{ro} = 0.3 - 0.4$ for α_{ox} values less than $\lesssim 1.5$ (probably tracing synchrotron emission, Padovani & Giommi 1995b) and with a diagonal branch (probably tracing inverse Compton emission) populated by LBL BL Lacs and by Flat Spectrum Radio Quasars (FSRQ). The region above $\alpha_{ro} = 0.2$ (radio-loud region) and in between the two main branches is less populated similarly to the case of Fig. 3 where only radio sources known before our sample was assembled are plotted. No new large population of objects filling previously unpopulated regions of the $\alpha_{ox} - \alpha_{ro}$ plane seems to emerge. This indicates that the dominant mechanisms producing electromagnetic radiation in the full sample of radio-loud objects are not different from those seen in known sources, that is Synchrotron and Synchrotron/Compton emission.

We have been able to statistically identify a large sample of extreme ($f_x/f_r > 3 \times 10^{-10}$ erg cm^{-2} s^{-1} Jy^{-1}) HBL BL Lacs with very small contamination ($\lesssim 15\%$) from other sources. We have named this survey *sedentary* since it can be used to draw conclusions about some of the cosmological properties of High Energy Peaked BL Lacs even without complete optical identification. This type of BL Lacs are typically found in X-ray surveys (e.g., EMSS, Stocke et al. 1991, EXOSAT HGLS, Giommi et al 1991, *Einstein* IPC Slew survey, Perlman et al. 1996). For the first time we have been able to assemble a sizable and well defined sample of HBL BL Lacs that is *radio* flux limited with a sensitivity limit that is nearly three orders of magnitude lower than the only existing complete sample of BL Lacs at radio frequencies (the 1Jy sample, Stickel et al. 1991).

The method presented here could also be extended to select large samples including a high percentage ($\sim 30 - 50\%$) of BL Lacs with less extreme HBL properties, although in this case follow up optical observations cannot be avoided.

The main result of this study is that our sample of HBLs shows a $\langle V_e/V_a \rangle = 0.42 \pm 0.02$. This value is somewhat dependent on the redshift assumed for the sources without redshift determination but even if this is taken to be twice as large as $\langle z \rangle \sim 0.25$ $\langle V_e/V_a \rangle$ is still below 0.5 at the 96% level. The space distribution of these objects appears then to be inconsistent with that of uniformly distributed population of sources. This result extends to the radio band earlier X-ray findings based on much smaller samples of BL Lacs discovered in *Einstein* and *ROSAT* X-ray images (Maccacaro et al. 1988, Morris et al. 1991, Wolter et al. 1994, Bade et al. 1998).

It is also interesting that the low (< 0.5) $\langle V_e/V_a \rangle$ values set in at $f_r \lesssim 20$ mJy (see Tab. 3), that is around the radio flux where the counts start to flatten. Both effects can be explained by a dearth of low-flux sources. No such dependence of $\langle V_e/V_a \rangle$ on radio flux is present for the radio-quiet control sample.

These results have been interpreted as evidence of a "negative" amount of cosmological evolution, that is BL Lacs would be more numerous or more luminous now than in the past. Padovani & Giommi (1995b) noticed that this non-uniform distribution could be explained by the fact that at higher redshifts, and therefore higher rest-frame frequencies, one would be more likely to be above the peak of the Synchrotron emission, thereby "losing" objects. In other words, X-ray selection would preferentially pick-up nearby, high energy peaked HBL BL Lacs (which are much stronger X-ray emitters than LBLs), whereas higher luminosity/redshift objects would be more difficult to detect, causing an apparent lack of X-ray selected BL Lacs at high redshift. Padovani & Giommi (1995b), however concluded that at that time this hypothesis was not supported by sufficient unbiased experimental evidence.

Another possible reason for this peculiar behavior could be related to different evolution rates of the thermal (disk + emission lines) and the non-thermal (synchrotron/Compton) components in blazars. If the thermal component is characterized by a more pronounced cosmological evolution then sources at high redshift would be called FSRQ more frequently than at low redshift (or, equivalently, they would be classified as BL Lacs less frequently than at low redshift). One such scenario has been proposed by Cavaliere & Malquori (1999) where the slowly evolving synchrotron/Compton component is produced via the Blandford-Znajek (1977) process, characterized by long timescales while the QSO/thermal component is instead short lived and is triggered by merging events that were more frequent in the past. This scenario however would require a tight connection between BL Lacs and FSRQ, which at the moment does not seem to be supported by observations (see, e.g., Urry & Padovani 1995).

Fossati et al. (1998), studying flux limited samples of BL Lacs selected at different frequencies reached the conclusion that synchrotron emission in powerful BL Lacs peaks at IR frequencies whereas in less luminous objects the peak is located near the X-ray band. Ghisellini et al. (1998) have interpreted this as the consequence of an intrinsic correlation between the Lorentz factor of the electrons emitting near the synchrotron peak and the energy density present in the emitting region. In this model most low luminosity BL Lacs would be HBLs and most high luminosity BL Lacs would be LBLs. This is a strong conclusion that can be tested with our results. The radio LogN-LogS plotted in Fig. 5 shows that the fraction of extreme HBLs compared to the expectation for all types of BL Lacs is always small ($\sim 2\%$) and roughly constant down to the 3.5 mJy limit of our survey. This seems to be inconsistent with the expectations of the Fossati et al. (1998) and Ghisellini et al. (1998) model that instead predicts that the percentage of HBL BL Lacs must significantly increase with decreasing radio luminosity until it becomes the dominant component at low radio fluxes/luminosities. For example, the total HBL fraction is predicted to go from 5% at 1 Jy, to 16% at 100 mJy, to 38% at 10 mJy, with an overall increase of a factor of 8 (Fossati et al. 1997). This implies a steep radio logN-logS of HBLs that is ruled out by the actually measured logN-logS shown in Fig. 5. Any steepening must start below our survey flux limit. Two points should however be noted: 1. our survey includes extreme HBLs, i.e., objects with X-ray-to-radio flux ratios $f_x/f_r > 3 \times 10^{-10}$ erg cm^{-2} s^{-1} Jy^{-1}(the dividing line between HBLs and LBLs is generally taken to be around $f_x/f_r \sim 1 \times 10^{-11}$ erg cm^{-2} s^{-1} Jy^{-1}; see, e.g., Padovani & Giommi 1995b). These however make up a substantial fraction of all HBLs (8/24 or 33% in the revised EMSS sample of Morris et al. 1991); 2. the radio counts for the whole BL Lac population are based on the 1 Jy sample and on a beaming model (see Padovani & Giommi 1995b for details). They therefore represent our best guess for the number density of BL Lacs at low radio fluxes but they still are an extrapolation. We note, however, that this extrapolation is in excellent agreement with the BL Lac number density derived from the S4 ($f_{5\mathrm{GHz}} \geq 0.5$ Jy; Stickel & Kühr 1994) and S5 ($f_{5\mathrm{GHz}} \geq 0.25$ Jy; Stickel & Kühr 1996) catalogs. The comparison will be on firmer grounds as soon as the radio counts for BL Lacs down to ~ 50 mJy will be available from DXRBS (Perlman et al. 1998).

Ghisellini (1998), following the BeppoSAX detection of synchrotron peaks at hard X-ray energies in the TeV BL Lacs MKN 501 (Pian et al. 1998) and 1ES2344+514 (Giommi et al. 1998), presented a scenario where the peak of the synchrotron emission in BL Lacs might reach very high energies, possibly well into the MeV region. Some of these objects, except perhaps the most extreme ones (which would be below our radio threshold) could be included in our sample, which is selected to have very high f_x/f_r ratios.

Forty-eight objects in our sample have $f_x > 10^{-11}$ erg cm^{-2} s^{-1} (thirty-five of these are known BL Lacs). Under the assumption that the inverse Compton and synchrotron powers are of the same order (see, e.g., Fossati et al. 1998), Stecker, de Jager & Salamon (1996) have shown that $\nu_{\mathrm{TeV}} f_{\mathrm{TeV}} \sim \nu_x f_x$. These sources (at least the low-redshift one, because of intergalactic absorption) could then be detected at TeV frequencies (especially during flares) even with the present generation of Cerenkov telescopes.

Finally, we stress that "statistical" methods of source identification of the kind described in this paper (i.e., selecting rare sources with [almost] unique spectral energy distribution or location in a multi-parameter, multi-frequency space) will have to become more and more common in the near future. Given the large number of up-coming surveys at various frequencies, in fact, it will be increasingly difficult to conduct surveys the "classical" way, as the number and faintness of the objects involved will require exceedingly large amounts of telescope time to secure optical spectroscopy and identification.

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